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Adult Age Differences in Subjective Context Retrieval in Dual-List Free Recall

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Abstract

Age-related episodic memory deficits imply that older and younger adults differentially retrieve and monitor contextual features that indicate the source of studied information. Such differences have been shown in subjective reports during recognition and cued recall as well as process estimates derived from computational models of free recall organization. The present study extends the subject report method to free recall to characterize age differences in context retrieval and monitoring, and to test assumptions from a context-based computational model. Older and younger adults studied two lists of semantically related words and then recalled from only the first or second list. After each recall, participants indicated their subjective context retrieval using remember/know judgments. Compared to younger adults, older adults showed lower recall accuracy and subjective reports of context retrieval (i.e., remember judgments) that were less specific to correct recalls. These differences appeared after first-recall attempts. Recall functions conditioned on serial positions were more continual across correct recalls from target lists and intrusions from non-target lists for older than younger adults. Together with other analyses of context retrieval and monitoring reported here, these findings suggest that older adults retrieved context less distinctively across the recall period, leading to greater perceived similarity for temporally contiguous lists.

Keywords

aging; context; episodic memory; free recall; recollection

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In daily life, people often need to recall details from specific events. However, memory is imperfect, especially when past events are similar. In these situations, older adults often show less precise remembering than younger adults (e.g., Greene & Naveh-Benjamin, 2020, 2022). Suppose that the older adult visited the same restaurant for lunch on two separate days, and some menu items changed across occasions. When planning their next visit to that restaurant, memory for the recent menu items could guide their decision. Recalling specific items requires targeting memories from the recent occasion, and this could be helped by retrieving peripheral features that contextualize the main event content, such as the weather and lunch partner that day. In this instance, an older adult may have less success remembering menu items than a younger counterpart because the older adult has less precise memory for the earlier-event contexts.

Context refers to external and internal information associated with the main event content, such as physical environments, event timing, and thoughts and feelings (e.g., Bower, 1967; Estes, 1955; McGeoch, 1932). The example above illustrated the distinction between event content (menu items) and context (weather and partner). Memory for event details depends on the contextual overlap of current environmental features and earlier experiences (e.g., Smith & Vela, 2001). Age-related differences in contextual details, especially sources, may reflect differences in how context was attended to and retrieved (for reviews, see Balota et al., 2000; Spencer & Raz, 1995). When older adults report their experience of remembering context in recognition and cued recall tasks, they falsely recollect event details, attributing these details to the wrong sources, more often than younger adults (e.g., McCabe et al., 2009; Parkin & Walter, 1992). Although verbal theories propose that older adults should show poorer memory than younger adults in tasks requiring more self-initiated retrieval of context, such as free recall (Craik, 1986), there is a lack of more direct evidence of age differences in context retrieval in free recall using subjective reports. Also, a context-based model of age-related free recall differences (Healey & Kahana, 2016) has shown that similarities and differences in recall levels and response ordering can be described by process estimates showing that older adults have less access to context (retrieval) and are less subjectively aware (monitoring) of temporal sources when context is retrieved. But no studies to our knowledge have examined model predictions using subjective reports. This is necessary to further refine assumptions from context-based models and to inform how potential age differences in retrieval and monitoring of context unfold over time.

These gaps in the literature motivated two primary aims in the present study. We used subjective reports of retrieved context to (1) characterize age-related differences in the subjective experience of context retrieval in free recall assumed by verbal theories and (2) compare the dynamics of these reports to predictions from a leading context-based computational model of free recall. We did this using a dual-list free recall task that relied heavily on temporal context retrieval. Participants studied two lists of words with semantic associations within and between lists, then attempted to recall words from only the first or second list. We assessed context retrieval and monitoring using the

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remember/know procedure (Tulving, 1985) with instructions to reply "remember" when features indicating list membership of recalled items were retrieved and "know" when no context was accessible. The hypotheses for this study were motivated by studies of age-related differences in context retrieval using subjective reports, context-based computational models, and retrieval dynamics that we selectively review in what follows.

Age Differences in Subjective Context Retrieval

Studies assessing subjective reports of recollection suggest that older adults experience impaired retrieval and monitoring of contextual features. This has been measured using the remember/know procedure (Rajaram, 1993; Tulving, 1985) in which participants indicate if a retrieval attempt elicited the experience of *remembering* contextual details from the study event or *knowing* that it appeared earlier without remembering contextual details. This procedure has shown age-related recognition differences with older adults reporting proportionally fewer correct "remember" recognitions and more "remember" false alarms than younger adults (Koen & Yonelinas, 2016; McCabe et al., 2009; Parkin & Walter, 1992; Prull et al., 2006). Similar findings in cued recall have shown more false remembering after forced-guessing errors (Meade & Roediger, 2006) and intrusions induced by misleading test primes (Jacoby et al., 2005).

Older adults' susceptibility to false recollection has also been shown in source memory tasks (Dodson et al., 2007a, 2007b). For example, after learning statements from two sources, older and younger adults performed an old/new recognition task in which they indicated whether statements judged as old were read in a male or female voice and rated their confidence in their judgment accuracy (Dodson et al., 2007a). When item memory was equated between groups, source confidence was calibrated more poorly for older adults, reflecting more high confidence source errors. This pattern was replicated in cued recall. Collectively, these findings suggest that older adults experience more false recollections, a hallmark of impaired context monitoring. The results also suggest that in the present dual-list free recall task, older adults should more often falsely recollect intrusions from non-target lists as being from target lists.

Free Recall Characteristics in Older and Younger Adults

Studies of age differences in free recall strongly suggest that older adults retrieve and monitor context less well than younger adults. Older adults show lower correct recall from target sources and more intrusions from non-target sources than younger adults (e.g., Craik, 1968; Kahana et al., 2002, 2005; Schonfield & Robertson, 1966; Wahlheim et al., 2016; Wahlheim & Huff, 2015). As indicated by serial position curves (SPCs) used to measure recall probabilities as a function of the original list input position of the items, the age-related deficit in correct recall is typically uniform across input positions (Kahana et al., 2002; Parkinson et al., 1982), but sometimes is reduced in recall from the most recent study items (e.g., Craik, 1968; Raymond, 1971). These mixed findings may reflect the extent to which task details encourage particular strategies for retrieving context from certain portions of the list at the beginning of the recall period.

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Characteristics of recall initiation in younger and older adults are compatible with the possibility of strategic differences. Recall initiation that is assumed to reflect the initial retrieval of a target source context can be examined by computing the probability of first recall (PFR) from each serial position of the study list. PFR functions are sometimes comparable for older and younger adults in showing primacy effects when recalling immediately after studying and recency effects when recall begins after some delay (Golomb et al., 2008; Healey & Kahana, 2016; Kahana et al., 2002; Wahlheim & Huff, 2015). However, those functions have differed between age groups in dual-list tasks when participants were instructed to report all words that came to mind during recall (Wahlheim et al., 2017; Wahlheim & Garlitch, 2020). These findings suggest that initial context retrieval can be similar for younger and older adults, but such reinstatement is unlikely to be comparable when trials include interference from adjacent lists and context monitoring to reject intrusions is not considered. Such age differences may reflect the efficacy of control mechanisms underlying working memory capacity (cf. Unsworth & Engle, 2007).

Beyond first recalls, output profiles characterizing relative differences in recall from target and non-target lists can also reveal differences in the ability to repeatedly retrieve target list context. Output profiles show recall probabilities for various response types at each recall position (Unsworth et al., 2013; Wahlheim & Huff, 2015). The few studies characterizing age differences in output profiles showed that correct recalls decreased and intrusions increased far more rapidly over the first few retrieval attempts for older than younger adults (Wahlheim et al., 2017; Wahlheim & Huff, 2015). Allowing older adults to overtly reject intrusions reduces but does not always eliminate age differences in the rapid increase of intrusions (Wahlheim et al., 2017; Wahlheim & Garlitch, 2020). Taken with first-recall characteristics, these findings suggest that even when both age groups begin recall similarly, presumably by relying on the currently activated context, older adults are less likely to engage in reinstatement of earlier-activated context on subsequent recalls and often do not monitor source context of recalls as well as younger adults.

Modeling Age Differences in Context Retrieval and Monitoring

A context maintenance and retrieval (CMR2) model has been proposed to identify the mechanisms underlying age-related free recall differences (Healey & Kahana, 2016). The core assumption derived from temporal context models (e.g., Howard & Kahana, 2002; Lohnas et al., 2015; Polyn et al., 2009; Sederberg et al., 2008) is that item-to-context associations and subsequent context retrieval determine the recall characteristics described above. For example, primacy effects when recalling after a delay are assumed to occur because early study items have stronger item-to-context associations (also see, Lehman & Malmberg, 2013). Further, recency effects when recalling immediately after study are accounted for by the similarity between end-of-study and beginning-of-test contexts (e.g., Howard & Kahana, 2002). CMR2 showed that age differences in free recall were accounted for by four component processes (Healey & Kahana, 2016). Older adults showed **(i)** poorer sustained attention, suggesting that they attended well initially but could not sustain attention during subsequent encoding. Older adults showed **(ii)** slower context drift at retrieval that presumably led to poorer specification of cues to constrain retrieval. Once items were retrieved, older adults required **(iii)** less evidence for deciding whether an item

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was from the target context and **(iv)** exhibited a noisier evidence accumulation process that together accounted for poorer intrusion rejection (cf. Kahana et al., 2005).

Although CMR2 accounts for many of the recall characteristics from a task requiring free recall of single lists immediately after study, few studies have tested predictions from this and other variants of temporal context models in other free recall tasks, and none have examined subjective context retrieval and monitoring. The only study to examine age differences in monitoring processes used externalized free recall procedures that measure decisions, but not subjective experiences of retrieving contextual features (Kahana et al., 2005). In the present study, we generalize predictions based on the component processes that propose (ii) slower contextual drift and (iv) poorer monitoring of intrusions to account for age-related differences in a dual-list free recall task that includes a measure of subjective context retrieval (i.e., the remember/know procedure).

Assessing Context Retrieval in Free Recall

Context retrieval in free recall has been assessed using various combinations of subjective reports, characterization of retrievals, and modeling. Although free recall has been assumed to reflect only context-based retrievals (e.g., Aggleton & Brown, 1999; Quamme et al., 2004), much evidence suggests that context retrieval can vary across recalls. For example, participants have assigned both remember and know judgments to recall responses (Arnold & Lindsay, 2002; Hamilton & Rajaram, 2003; Mickes et al., 2013; McDermott, 2006; Tulving, 1985). Also, estimates of context-based retrieval in free recall derived from subjective reports (remember/know) and a process dissociation procedure (McCabe et al., 2011) have been shown to vary with manipulations affecting context retrieval (e.g., divided attention). Studies have also used remember/know judgments to characterize subjective context retrieval across recall attempts for comparison with model assumptions. For example, context-based models assume that recalling responses consistent with their study order reflects context retrieval (e.g., Howard & Kahana, 2002). This has been shown to occur more for remembered than known recalls, suggesting that context was retrieved with remembered recalls (Sadeh et al., 2015, 2018). However, free recall organization does not always follow context-based model predictions, such as when remember and know recalls show comparable primacy effects in PFRs and SPCs (Sadeh et al., 2015). These patterns are incompatible with the assumption that primacy effects reflect stronger item-to-context associations for first-studied items (e.g., Healey & Kahana, 2016; Lehman & Malmberg, 2013) and can be accounted for by views emphasizing a role for rehearsal frequency (e.g., Rundus, 1971; Tan & Ward, 2000).

The inconsistent support for predictions from context-based models about the role of context retrieval in recall organization highlights the need for empirical tests to further constrain model assumptions. This is especially true because prior studies of retrieval characteristics conditioned on subjective context retrieval included only younger adults and used trials with delays between study and recall tests. Since context retrieval and various retrieval characteristics are assumed to differ with age (e.g., Healey & Kahana, 2016) and the delay between study and test trials (e.g., Howard & Kahana, 1999; Kahana, 2002), the potential limitations of CMR2 could be examined using empirical tests of older and younger adults

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with trials that also include recall tests that appear immediately after study lists. The latter will provide data relevant to debates about the role of contextual mechanisms in recency effects on tests at various delays (e.g., Davelaar et al., 2005).

The Present Study

The present study bridges the literatures above by examining older and younger adults' subjective context retrieval and retrieval characteristics in dual-list free recall including words with semantic associations within and between lists. Note that these associations placed high demands on source context retrieval to distinguish recalls from each list. We expected fewer correct recalls and more intrusions for older adults, suggesting an age difference in context retrieval and monitoring (cf. Wahlheim & Huff, 2015). We thus expected older adults to also show poorer context monitoring in the form of proportionally more remembered intratrial intrusions, a type of false recollection (cf. McCabe et al., 2009; Meade & Roediger, 2006).

Our hypotheses regarding retrieval characteristics across recalls were motivated by earlier findings from similar tasks. We expected the shapes of SPCs and PFRs to replicate earlier studies showing more primacy when recalling from the first list and more recency when recalling from the second list (e.g., Healey & Kahana, 2016; Howard & Kahana, 2002; Lehman & Malmberg, 2013) For SPCs, older adults may show uniformly lower correct recall across all serial positions (e.g., Kahana et al., 2002; Parkinson et al., 1982), but this difference may also be smaller for recency positions on immediate tests (e.g., Craik, 1968). By comparing SPCs for both correct recall and intratrial intrusion, we were also able to examine the response accessibility across positions traversing boundaries between lists. If context drifts more slowly for older adults (Balota et al., 1989), leading more of the same features to become associated with adjacent events (Campbell et al., 2014), then their SPCs transitioning between correct recalls and intrusions should show less separation across list boundaries. However, if context drifts more slowly for older adults only at retrieval (Healey & Kahana, 2016), then such list separation should be comparable for both age groups. Further, age differences in context retrieval may be less pronounced when people are initiating recall than on subsequent recall attempts shown by more comparable PFRs than output profiles for older and younger adults. We characterized the measures conditioned on subjective reports to test CMR2 predictions. Primacy and recency in SPCs and PFRs should be more prominent for remembered than known recalls if those effects reflect stronger item-to-context associations and greater contextual overlap, respectively, in those positions. Finally, remembered recalls should decline faster across the recall period for older adults if they experience poorer context retrieval that leads to less effective cuing for subsequent recalls.

Method

Participants

The participants were 24 younger adults, ages 18–21 (M_{age} = 19.13 years, SD = 0.99) and 24 older adults, ages 66–84 (M_{age} = 71.29 years, SD = 5.33). Younger adults were recruited from the participant pool in the Department of Psychological and Brain Sciences at

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Washington University in St. Louis and were compensated with course credit or $10. Older adults were recruited from the St. Louis community through participant pools maintained by the School of Medicine and Department of Psychological and Brain Sciences at Washington University in St. Louis and were compensated with $15. Older adults had more self-reported years of education ($M = 17.29$, $SD = 3.07$) than younger adults ($M = 13.08$, $SD = 1.14$), $t(46) = 6.29$, $p < .01$. Older adults also had higher vocabulary scores ($M = 36.46$, $SD = 2.15$) than younger adults ($M = 34.38$, $SD = 2.14$), $t(46) = 3.37$, $p < .01$, as measured by the vocabulary test from the Shipley Institute of Living Scale (Shipley, 1986). The experimental procedures reported below were approved by the Institutional Review Board at Washington University in St. Louis.

Materials

The materials were 288 words (eight exemplars from 36 different categories) from the Van Overschelde et al. (2004) category norms. For example, the category insects contained exemplars such as bee, spider, and grasshopper (for more examples, see Figure 1). Words ranged from 3–11 letters in length ($M = 6.10$, $SD = 1.97$). The exemplar typicality ratings provided by these norms ranged from 2–20 ($M = 5.50$, $SD = 3.47$). Study lists were created by first setting 12 groups of 24 words that contained eight exemplars from three different categories in each group. The groups were matched on word length and typicality ratings for each category as closely as possible given the constraints of the material set. Then, each group was divided to create List 1 and List 2 (12 words each). Lists within trials included unique exemplars from the same categories. The experiment included three blocks, each with two trials per recall list condition (four total). This resulted in 12 study-test trials total (six per recall condition). Each trial included List 1, List 2, and a recall period (Figure 1). Word groups were assigned to the same blocks across experimental formats. For counterbalancing, groups appeared equally often in study and recall list condition across participants. There were eight experimental formats. The orders of recall list conditions in blocks, and words in lists, were randomized.

Procedure

Older and younger adults completed 12 study-test list trials in the experiment. On each trial, participants were told to study two lists of words and to attend to the words on each list equally. Participants were told that they would be asked to recall from only one study list but would not be told which list until the recall phase. At recall, participants were also told to rate their confidence (low, medium, or high) that each recall was from target list and give high ratings only when they were certain. Confidence judgments were an exploratory measure (see Supplemental Material). Participants were given instructions for remember/know judgments from Rajaram (1993). They were told to indicate “remember” when they consciously recollected the word in the target list and to indicate “know” when they did not recollect it. They were given the example, “if someone asked you what book you last read or what movie you last saw, you would typically respond in the “remember” sense because you would consciously recollect some aspects of the experience. However, if someone asked you for your name, you would typically respond in the “know” sense without becoming consciously aware of a particular earlier experience.”

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Before the experiment, participants completed two practice trials, each comprising two lists of 10 unrelated words and a recall test from each recall list condition. For the practice and experimental trials, the prompts “List 1” and “List 2” appeared for 3 s before each list. Each study item appeared individually for 1 s with a 1 s interstimulus interval (ISI). Participants read each word aloud. After List 2, the prompt “Recall List 1” or “Recall List 2” appeared for 2 s, then the recall period began. Younger adults typed their responses, and an experimenter typed older adults’ responses. This difference was necessary for older adults to make multiple responses for each recall. Following each recall, participants rated their confidence and made remember/know judgments with key presses: (1) low, (2) medium, (3) high; (R) remember, (K) know. Each recall period was 120 s.

Analytic Approach

We examined summary scores of response frequencies for correct recalls, intratrial intrusions, and joint frequencies of remember and know judgments for these responses. The frequencies for correct recalls and intratrial intrusions were the number of responses in each recall list condition averaged across trials. The joint frequencies of correct recalls and intratrial intrusions given remember and know judgments were calculated as the number of joint responses of interest in each recall list condition averaged across trials. To examine retrieval characteristics, we computed SPCs, PFRs, and output profiles. SPCs and PFRs were probabilities of correct recalls and intratrial intrusions conditioned on serial position for all recalls (SPCs) and only the first recall (PFRs). Given the modest samples, we smoothed these functions, averaging across every three positions, except for the first and last positions, which were not included in the averaging. We examined these functions for correct recalls and intrusions for all responses together and separated by remember/know judgments for only correct recalls due to sparse observations for intrusions. We computed output profiles by conditioning responses on each output position across the recall period, up to position 12 beyond which observations were sparse.

For all analyses except for summary scores, we fitted separate models to List 1 and List 2 recall tests because we did not test hypotheses about age differences between those conditions. Analyses were conducted using R software (R Core Team, 2020). The data were fitted with linear and generalized linear mixed-effects models using the *lmer* and *glmer* functions from the *lme4* package, respectively (Bates et al., 2015). Unless noted otherwise, all models included by-participant and by-trial random intercept effects and age as a fixed effect. Hypothesis testing was done using the *Anova* function from the *car* package (Fox & Weisberg, 2019), and pairwise comparisons were made using the *emmeans* function from the *emmeans* package (Lenth, 2020) with the Tukey correction for multiple comparisons. The significance level was α = .05.

Results

Summary Scores

We expected to replicate prior findings from dual-list free recall showing fewer correct recalls and more intratrial intrusions for older than younger adults (e.g., Wahlheim et al., 2016). To test this, we fitted separate Age × Recall List models to each response type

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(Figure 2, left panels). The model for correct recalls indicated a significant effect of Age, $\chi^2(1) = 54.68$, $p < .001$, showing higher correct recall for younger than older adults. No other effects were significant, *largest* $\chi^2(1) = 2.73$, $p = .10$. The model for intratrial intrusions indicated significant effects of Age, $\chi^2(1) = 20.47$, $p < .001$, Recall List, $\chi^2(1) = 19.05$, $p < .001$, and a significant interaction, $\chi^2(1) = 6.06$, $p = .01$, showing more intrusions for older than younger adults, and a larger age difference for List 2 recall, $t(69.80) = 5.14$, $p < .001$, than List 1 recall, $t(69.80) = 3.00$, $p < .01$. The intrusion difference indicated that older adults were more susceptible to proactive interference from List 1 exemplars when recalling from List 2. Extra-experimental intrusions, prior trial intrusions, and repetitions, were quite rare ($M \leq 0.36$ per trial).

Remember/Know Judgments

To address our first primary aim of the study, which was to characterize age differences in subjective context retrieval in free recall, we assessed age differences in joint frequencies of correct recalls and intratrial intrusions and remember/know judgments (Figure 2, middle and right panels). This allowed us to examine age differences in context monitoring that are assumed by both verbal theories and context-based models. To do so, we fitted separate Age × Recall List models for each response and judgment combination.

Correct Recalls—We expected older adults to show fewer remember-correct recalls than younger adults, consistent with studies showing age-related deficits in recollection-based recognition (e.g., McCabe et al., 2009). The model for remember-correct recalls (top middle panel) indicated a significant effect of Age, $\chi^2(1) = 5.08$, $p = .02$, supporting our hypothesis that younger adults would exhibit higher remember recalls than older adults. No other effects were significant, *largest* $\chi^2(1) = 0.46$, $p = .50$. The model for know-correct recalls (top right panel) indicated significant effects of Age, $\chi^2(1) = 4.69$, $p = .03$, and Recall List, $\chi^2(1) = 5.20$, $p = .02$, and no significant Age × Recall List interaction, $\chi^2(1) < .01$, $p = .92$. Younger adults reported more know recalls than older adults, and there were more know recalls from List 2 than List 1. The significant effect of Recall List is consistent with accounts positing that retrieval of recent items can be supported by a short-term activation buffer without retrieving context (Davelaar et al., 2005). We return to this point when describing the PFR findings below.

Intratrial Intrusions—We also expected to replicate prior findings showing more false recollection in older than younger adults (e.g., McCabe et al., 2009) for remember-intratrial intrusions. The model for remember-intratrial intrusions (bottom middle panel) indicated significant effects of Age, $\chi^2(1) = 16.84$, $p < .001$, and Recall List, $\chi^2(1) = 29.28$, $p < .001$, and a significant interaction, $\chi^2(1) = 7.18$, $p < .01$. The interaction supported our hypothesis in showing more remember intrusions for older than younger adults with a larger age difference for List 2 recall, $t(55.90) = 4.72$, $p < .001$, than List 1 recall, $t(55.90) = 3.09$, $p < .01$. The larger age difference for List 2 recall suggests that older adults' greater susceptibility to proactive interference manifested in more false recollection of studied exemplars from a remote source. Given that items were semantically associated between lists, participants were likely reminded of List 1 exemplars during List 2 study, thus increasing the accessibility of List 1 items. Older adults' greater susceptibility to

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proactive interference from List 1 may therefore reflect more source misattributions based on the strength of retrievals. We return to this point in the Discussion. The model for know-intratrial intrusions indicated no significant effects, *largest* $\chi^2(1) = 0.28$, $p = .59$.

Serial Position Curves

All Responses—Next, we decomposed overall recall performance to examine age-related differences in free recall characteristics to test predictions made by CMR2. We first calculated SPCs (Figure 3) for correct recalls to characterize age differences in correct response accessibility across serial positions. We expected to replicate primacy-oriented functions in List 1 recall and more recency-oriented functions in List 2 recall (Wahlheim & Huff, 2015). It was unclear whether age-related deficits would be consistent across all positions due to mixed evidence reported in the literature (for a review, see Healey & Kahana, 2016). We examined age differences using separate Age × Position models for each Recall List condition. The List 1 model indicated significant effects of Age, $\chi^2(1) = 44.47$, $p < .001$, and Position, $\chi^2(11) = 334.43$, $p < .001$, showing higher recall at all positions for younger adults and primacy effects for both groups. The interaction was not significant, $\chi^2(11) = 16.74$, $p = .12$. The List 2 model indicated significant effects of Age, $\chi^2(1) = 51.66$, $p < .001$, and Position, $\chi^2(11) = 710.04$, $p < .001$, and a significant interaction, $\chi^2(11) = 35.90$, $p < .001$. The position effect showed the expected recency effect for both groups. The interaction showed smaller age differences for the most recent item compared to other items and more extended primacy for younger than older adults, which are both incompatible with CMR2 (e.g., Healey & Kahana, 2016).

SPCs for intratrial intrusions (Figure 3) characterized the consequences of age differences in failed context retrieval and monitoring across positions using the same approach as for correct recalls. Both models indicated significant effects of Age and Position, *smallest* $\chi^2(1) = 4.66$, $p = .03$, and no significant interactions, *largest* $\chi^2(11) = 17.82$, $p = .09$. Despite the absence of interactions, the nominal pattern shows more temporal contiguity across lists for older adults (gray rectangle), suggesting that older adults were less sensitive to the context boundary between lists. This is consistent with the view that older adults experience slower context drift (Balota et al., 1989) and associate similar context with more events than younger adults (e.g., Campbell et al., 2014).

Correct Recall Responses Conditioned on Remember/Know Judgments—To assess potential age differences in retrieved context across serial positions, we examined correct recall SPCs conditionalized on remember and know judgments (Figure 4). We used separate Age × Position × Judgment (Remember vs. Know) models for each Recall List condition and do not describe redundant effects. For List 1, we expected larger primacy effects for remember than know recalls because context-based models propose that item-to-context associations should be strongest for items in early input positions (e.g., Healey & Kahana, 2016; Lehman & Malmberg, 2013). The model indicated significant effects of Age, Position, and Judgment, *smallest* $\chi^2(1) = 43.83$, $p < .001$, that were qualified by a significant Position × Judgment interaction, $\chi^2(11) = 57.38$, $p < .001$, showing significantly larger primacy effects for remember than know recalls. No other interactions involving Judgment were significant, *largest* $\chi^2(11) = 19.29$, $p = .06$. For List 2, we expected larger

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recency effects for remember than know recalls because there is a stronger match between the end-of-study contexts and beginning-of-test contexts (e.g., Howard & Kahana, 2002). The model indicated significant effects of Age, Position, and Judgment, *smallest* $\chi^2(1) = 51.11$, $p < .001$, showing primacy and recency effects in recall functions for both judgments. There were no significant interactions involving Judgment, *largest* $\chi^2(11) = 17.64$, $p = .09$. Therefore, the results for List 2 are incompatible with context-based model assumptions about the role of context in recency effects, as these effects appeared for acontextual know judgments.

Probability of First Recall Curves

All Responses—According to context-based models (e.g., Howard & Kahana, 1999; Kahana et al., 2002), PFRs can illuminate the contribution of context retrieval to initial recalls. We expected to replicate results from standard free recall tasks showing age-invariant primacy- and recency-oriented functions for recall from delayed and immediate tests (e.g., Golomb et al., 2008; Kahana et al., 2002) when recalling from List 1 and List 2, respectively. We used separate Age × Position models for each Recall List condition (Figure 5). For List 1, a significant effect of Position, $\chi^2(11) = 528.57$, $p < .001$, showed primacy-oriented functions for both groups. No other effects were significant, *largest* $\chi^2(11) = 6.84$, $p = .81$. For List 2, the model indicated no significant effect of Age, $\chi^2(1) = .07$, $p = .79$; but a significant effect of Position, $\chi^2(11) = 1773.10$, $p < .001$, showed recency-oriented functions for both groups. A significant interaction, $\chi^2(11) = 23.51$, $p < .01$, showed that older adults initiated recall from the last input position more than younger adults. This recency difference may reflect strategies associated with working memory differences, a point we return to in the Discussion.

Responses Conditionalized on Remember/Know Judgments—Consistent with predictions above for SPCs, we expected greater primacy and recency effects for remember than know recalls when recalling from List 1 and List 2, respectively. We tested these predictions using separate Age × Position × Judgment (Remember vs. Know) models in each Recall List condition (Figure 6) and do not report redundant effects. Supporting context-based model predictions, the model for List 1 indicated significant effects of Position, $\chi^2(11) = 468.73$, $p < .001$, and Judgment, $\chi^2(1) = 89.80$, $p < .001$, and a significant Position × Judgment interaction, $\chi^2(11) = 110.79$, $p < .001$, showing substantially larger primacy effects for remember than know judgments. No other effects were significant, *largest* $\chi^2(11) = 16.13$, $p = .14$. For List 2, the model indicated significant effects of Position, $\chi^2(11) = 1314.40$, $p < .001$, and Judgment, $\chi^2(1) = 6.40$, $p = .01$, and a significant Position × Judgment interaction, $\chi^2(11) = 28.66$, $p < .01$, showing slightly larger recency effects for remember than know judgments. The three-way interaction was not significant, $\chi^2(11) = 8.60$, $p = .66$. These results could be interpreted as supporting context-based model assumptions about the role of enhanced context retrieval in recency effects, but the slight difference in recency between remember and know conditions creates some ambiguity. An alternative interpretation of these results is that context-based retrieval was sufficient but not necessary to produce such recency effects in retrieval initiation. We consider this point in more detail in the Discussion.

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Output Profiles

All Responses—We characterized response production across recalls by examining output profiles. We expected to replicate prior work in showing that older adults experience a sharper decline in correct recalls and a more rapid increase in intrusions than younger adults (e.g., Wahlheim et al., 2017; Wahlheim & Garlitch, 2020). This pattern of results would also support the assumption from CMR2 that that older adults' retrieved context cues subsequent retrievals less effectively (Healey & Kahana, 2016). We used separate Age × Output models to compare output profiles for each response type in each Recall List condition (Figure 7).

Correct Recalls.

For List 1, significant effects of Age, $\chi^2(1) = 39.98$, $p < .001$, and Output, $\chi^2(11) = 815.62$, $p < .001$, and a significant interaction, $\chi^2(11) = 25.31$, $p < .01$, showed that correct recall declined faster for older than younger adults after the first retrieval attempt. For List 2, significant effects of Age, $\chi^2(1) = 49.32$, $p < .001$, and Output, $\chi^2(11) = 837.10$, $p < .001$, and a non-significant interaction, $\chi^2(11) = 18.41$, $p = .07$, showed a nominal trend similar to List 1 recall. Together, these results suggest that older adults sustained context representations less effectively across recalls, especially when the task required self-initiating retrieval from a study context that was more distinct from the test context (i.e., recall from List 1).

Intratrial Intrusions.

For List 1, significant effects of Age, $\chi^2(1) = 9.67$, $p < .01$, and Output, $\chi^2(11) = 38.50$, $p < .001$, and a significant interaction, $\chi^2(11) = 40.15$, $p < .001$, showed that intrusions from List 2 peaked earlier for older than younger adults and remained higher across outputs until the seventh output. For List 2, significant effects of Age, $\chi^2(1) = 17.68$, $p < .001$, and Output, $\chi^2(11) = 105.11$, $p < .001$, and a significant interaction, $\chi^2(11) = 50.07$, $p < .001$, showed a pattern similar to List 1, but with a larger early increase for older adults. This pattern provides a characterization of the time course of their heightened susceptibility to proactive interference.

Only Remember-Correct Recalls—We examined age differences in the sustainment of context retrieval across recalls by comparing profiles for only remember-correct recalls (Figure 8). Based on the remember/know instructions given to participants, we assumed these responses reflected retrieval of context that was mostly likely to include accurate source information. We did not have a priori hypotheses about where differences would be most apparent, so we relied on visual inspection to inform our analyses. This approach led us to compare output positions from 1–4 using separate Age × Output (1–4) models for each Recall Condition. For List 1, a significant effect of Output, $\chi^2(3) = 8.17$, $p = .04$, and a significant interaction, $\chi^2(3) = 14.35$, $p < .01$, indicated that younger adults sustained context retrieval across the first four positions, whereas older adults showed an immediate decline after the first position. For List 2, a significant interaction, $\chi^2(3) = 8.59$, $p = .04$, showed the same general pattern as in List 1 recall, except that the earlier decline for older adults occurred after the second recall. No other effects were significant, *largest* $\chi^2(3) =$

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7.50, p = .06. Together, these results are compatible with the assumption that older adults' lower overall recall partly reflects poorer sustained context retrieval across recalls (Healey & Kahana, 2016).

Discussion

The present experiment examined adult age differences in subjective reports of retrieved context in a dual-list free recall paradigm. The results showing more remember judgments to intratrial intrusions for older than younger adults, especially when recalling from List 2, suggested that older adults were more susceptible to false recollection. We found the expected primacy- and recency-oriented functions when examining characteristics of recall from the first and second list. Older adults showed uniformly lower recall across most serial positions than younger adults, but the differences were smaller for recency items from the second list. Older adults also showed less differentiation in correct recalls and intrusions across list boundaries. Recall initiation was mostly comparable for older and younger adults, but older adults started recall from the last position of the second list more than younger adults. Primacy effects in SPCs and PFRs were greater for remember than know judgments, and there was mixed evidence for this difference in recency effects. Finally, compared to younger adults, older adults' output profiles showed more rapid declines in correct recall across the recall period, especially when subjective context was retrieved across the first few outputs, and earlier peaks in intratrial intrusions. In what follows, we describe the implications of these findings for theories of age differences in free recall.

Age-Related Differences in Subjective Remembering

The current results further inform our understanding of age differences in subjective experiences associated with self-initiated retrieval. Studies using cued recall and recognition reported worse context retrieval and monitoring in older than younger adults, shown by more false recollections (Jacoby et al., 2005; McCabe et al., 2009; Meade & Roediger, 2006; Parkin & Walter, 1992; Prull et al., 2006) and high confidence source memory errors for older than younger adults (Dodson et al., 2007a, 2007b). We extended this work by showing that older adults experienced more false recollections in the form of remember judgments to intratrial intrusions, particularly when recalling from the more recent list. Together with their lower overall recall, these results suggest that older adults were less effective at retrieving and monitoring contextual details that distinguished between lists.

This diminished ability to distinguish lists was likely exacerbated by the shared semantic features among category exemplars in each list. These features may have led exemplars in the second list to remind participants of exemplars from the same categories in the first list (Jacoby & Wahlheim, 2013). This may have increased the extent to which subsequent recall required reinstatement of temporal contextual features about list membership (also see, Wahlheim & Garlitch, 2020). Under these conditions, older adults may have misattributed fluency driven by semantic context to indicate target-list membership when making remember judgments more often than younger adults. Consistent with this, older adults have been shown to rely less on source memory features when making remember judgments during recognition (Boywitt et al., 2012). Furthermore, older adults' poorer monitoring

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can sometimes be attributed to an over-reliance on the acontextual familiarity of generated responses and an under-reliance on details recollected from the study experience (Jacoby et al., 2001; Kelley & Sahakyan, 2003). Together, remindings in the second list and a relatively greater reliance on semantic rather than temporal context can help explain why older adults were more susceptible to proactive interference, as more intrusions from List 1 during List 2 recall were more often reported as being recollected.

Although the demands on temporal context reinstatement from the shared semantic context across lists contributed to the age differences in overall recall, attending to and using shared semantic context can aid memory in other situations. For example, studies of problem solving and inferences suggest that relying on specific or local contextual features may impair performance because the tasks require understanding global features (for a review, see Jacoby et al., 1994). Therefore, older adults may leverage shared semantic context to make generalizations in these situations, which could reduce age differences in performance.

Modeling Age Differences in Episodic Memory

According to the CMR2 model (Healey & Kahana, 2016), four mechanisms can explain age differences in free recall (Healey & Kahana, 2016). We tested predictions for two of them: slower contextual drift at retrieval that leads to worse reinstatement of context and a lower monitoring threshold for accepting intrusions. It follows from older adults' poorer context retrieval and monitoring that their subjective reports of retrieved context should be less related to recall accuracy. Further, their lower threshold for accepting intrusions should lead them to report more intrusions. Older adults did report more intrusions, and false recollections of those intrusions, than younger adults. Older adults also showed a more rapid decline in subjective context retrieval for correct recalls across the first several outputs. This is consistent with the prediction from CMR2 that older adults are impaired at retrieving context to effectively cue subsequent retrieval attempts.

CMR2 also proposes that differences in context drift rates at retrieval and thresholds for accepting intrusions can account for established patterns of age-related stability and differences in retrieval initiation and subsequent retrieval attempts. Studies have typically shown uniformly lower recall across positions in SPCs for older than younger adults (e.g., Kahana et al., 2002; Parkinson et al., 1982) and age-invariant recency-oriented PFRs (Golomb et al., 2008; Healey & Kahana, 2016; Kahana et al., 2002; Wahlheim & Huff, 2015). Here, however, we found smaller age differences in the recency portion of the SPCs when testing List 2 (also see Craik, 1968) and we also observed that older adults initiated List 2 recall more often with most recent item than younger adults (also see Wahlheim & Garlitch, 2020). These results are inconsistent with CMR2 predictions, thus suggesting that older adults had intact short-term memory (Craik, 1977) and/or were more likely to strategically initiate recall from the end of the list (see Healey & Kahana, 2016).

Age-related strategy differences in retrieval initiation across the recall period could be related to differences in working memory. Several studies examining the relationship between working memory capacity and free recall dynamics suggest that recall initiation patterns (Unsworth & Engle, 2007) and strategy use at both encoding and retrieval are related to differences in working memory capacity (WMC; e.g., Unsworth, 2016). Since

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older adults show lower WMC on average than younger adults (for a meta-analysis, see Bopp & Verhaeghen, 2005), the present PFR differences could partly reflect age-related differences in the strategic approach to initiating retrieval. This could be tested by including WMC and strategy report measures and examining their association with retrieval characteristics in both age groups.

Finally, we also found that older adults showed less temporal separation in the SPCs for correct recalls and intratrial intrusions that traversed list boundaries. While this is consistent with the idea that older adults experience slower contextual drift (Balota et al., 1989), it is inconsistent with the proposal from CMR2 that older adults experience changes in contextual drift at retrieval but not encoding (Healey & Kahana, 2016). More generally, the present findings are mostly compatible with CMR2, but the points of inconsistency suggest that future modeling efforts should account for age differences in recall from remote sources, as CMR2 was built to account for recall from recent sources (but see Healey & Wahlheim, 2021).

The Role of Context Retrieval in Free Recall Characteristics

In addition to informing predictions about age differences in free recall, the present findings have implications for other key assumptions regarding some aspects of free recall characteristics. Some models propose that primacy and recency effects reflect enhanced retrieval of context associated with items studied in early and more recent positions, respectively (e.g., Healey & Kahana, 2016; Howard & Kahana, 2002; Lehman & Malmberg, 2013). It follows that such effects should be greater for context-based retrievals (i.e., remembered recalls) than acontextual retrievals (i.e., known recalls). But other accounts emphasizing rehearsal processes propose that primacy is driven by additional rehearsals of items from early serial positions (Rundus, 1971; Tan & Ward, 2000) while recency reflects retrieval of items activated in a short-term buffer without the need for context retrieval (Davelaar et al., 2005). This suggests that primacy and recency effects should not differ for remember and know judgments, which has been shown in prior work in delayed free recall tests with younger adults (Sadeh et al., 2015).

Here we found mixed evidence for the role of context-based retrieval in primacy and recency effects. First, when examining both SPCs and PFRs for delayed tests, primacy effects were greater for remember than know judgments. These findings contradict the results from Sadeh et al. (2015) but support the assumption from context-based models that primacy effects occur because of enhanced item-to-context binding for early input positions that can later be retrieved when initiating recall (Healey & Kahana, 2016; Lehman & Malmberg, 2013). We also found that recency effects were observed for both remember and know SPCs, and recency effects in PFRs were only slightly greater for remember than know recalls. Collectively, these results are somewhat inconsistent with the context-based model assumption that recency effects reflect the match between study-list and time-of-test contexts, and instead suggest that such effects rely more on retrieval from a short-term buffer (Davelaar et al., 2005). One explanation for the presence of recency effects in both contextual and acontextual recalls could be that people may still use context retrieval when recalling recency items, but this may occur rarely.

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Limitations

There are limitations when using the remember/know procedure to measure context retrieval. Some researchers propose that remember and know judgments distinguish between recollection and familiarity (for a review, see Umanath & Coane, 2020) while others suggest that these judgments capture differences in unidimensional signal strength (e.g., Wixted & Mickes, 2010). Furthermore, others have argued that whether there are age differences in these judgments can depend on the instructions given to participants (e.g., Koen & Yonelinas, 2016; Yonelinas, 2001). To mitigate the concern about instructions, we followed recommendations to use strict instructions in the present study. Given that our results were sensible in suggesting that older adults experienced a context retrieval deficit in the form of fewer remember judgments to correct recalls and more false remember judgments to intratrial intrusions, we are comfortable asserting that the judgments used here distinguished reasonably well between contextual and acontextual retrieval. But of course, converging evidence is required to bolster this assertion. Future work could implement think-aloud protocols (McCabe et al., 2011) and/or response justifications (Dobbins & Kantner, 2019) to evaluate the subjective contents of retrievals.

There are also limitations to the procedure and materials used here. While the retention intervals for List 1 recall trials were generally consistent with delayed free recall tasks (e.g., Howard & Kahana, 1999; Kahana et al., 2002), the present task unfolded over a relatively short timeframe compared to everyday recall situations. Additionally, we used this task specifically to characterize retrieval characteristics for comparison with results that have been the focus of formal modeling efforts. Furthermore, although the dual-list procedure allowed us to examine age differences in recall of isolated events, which mimics daily life, word-list recall is not identical to everyday memory experiences that incorporates multimodal information. Future studies could address this with using subjective report measures in tasks using more naturalistic stimuli.

Conclusion

The present study showed age-related deficits in retrieval and monitoring of context in older adults' subjective reports in free recall. Consistent with other studies of recognition and cued recall, older adults reported more false recollection than younger adults. Although the retrieval characteristics showed that both groups initiated retrieval in mostly comparable ways, older adults were less effective in retrieval and monitoring of context on subsequent retrieval attempts compared to younger adults. By examining the retrieval characteristics for remember and know judgments, we showed that primacy effects when recalling from the first list were largely driven by contextual retrieval. However, the results showing recency effects when recalling recently studied information for both judgment types suggest that both contextual and non-contextual mechanisms supported those retrieval patterns. Collectively, the present findings provide another characterization of age differences in recall from distinct but related episodes that further constrain theoretical models of age differences in episodic memory.

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Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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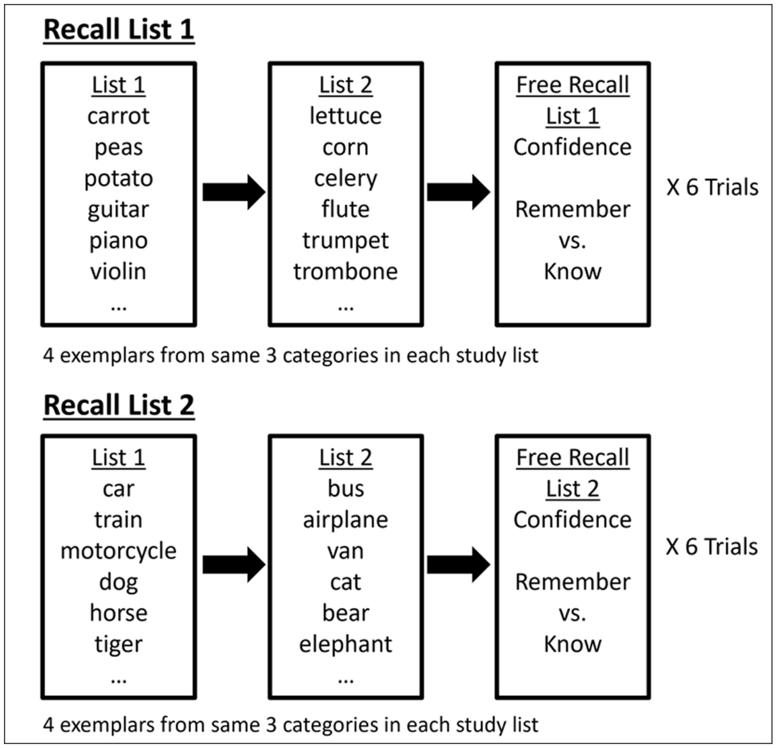

Figure 1. Experimental Design Schematic

Note. Schematic of the procedure for the dual-list free recall task. Participants completed 3 blocks of four trials (12 trials total) with each block including two trials for each of the recall conditions. Although the schematic above only includes three exemplars per list, the actual experiment included four exemplars from three categories per list (12 words total). Words were presented within their respective categories above to demonstrate the list composition but were randomized within lists for the experimental trials.

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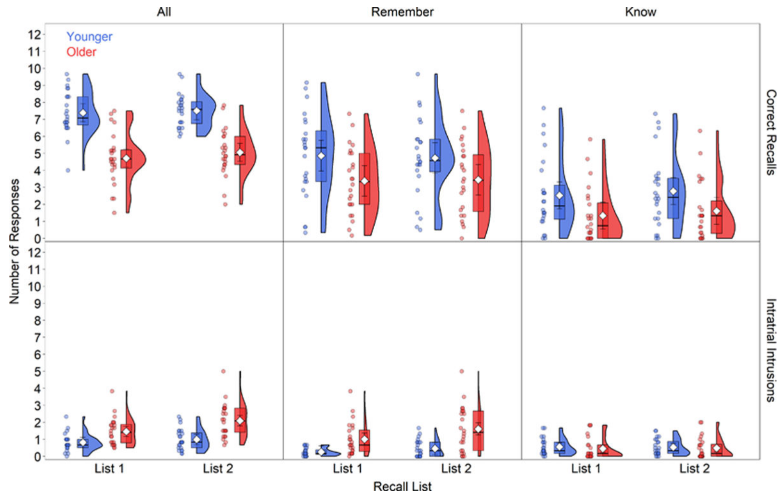

Figure 2. Correct Recalls and Intratrial Intrusions Overall and for Remember/Know Judgments

Note. Mean frequencies of correct recalls (top panels) and intratrial intrusions (bottom panels) for all responses (left panels) and joint probabilities of responses given remember (middle panels) and know judgments (right panels) in each recall list condition for younger and older adults. Colored points show individual participant frequencies, the widths of the half violin plots show the proportion of data at each frequency, box plots show medians and interquartile ranges, white diamonds show model-estimated frequencies, and corresponding error bars are 95% confidence intervals.

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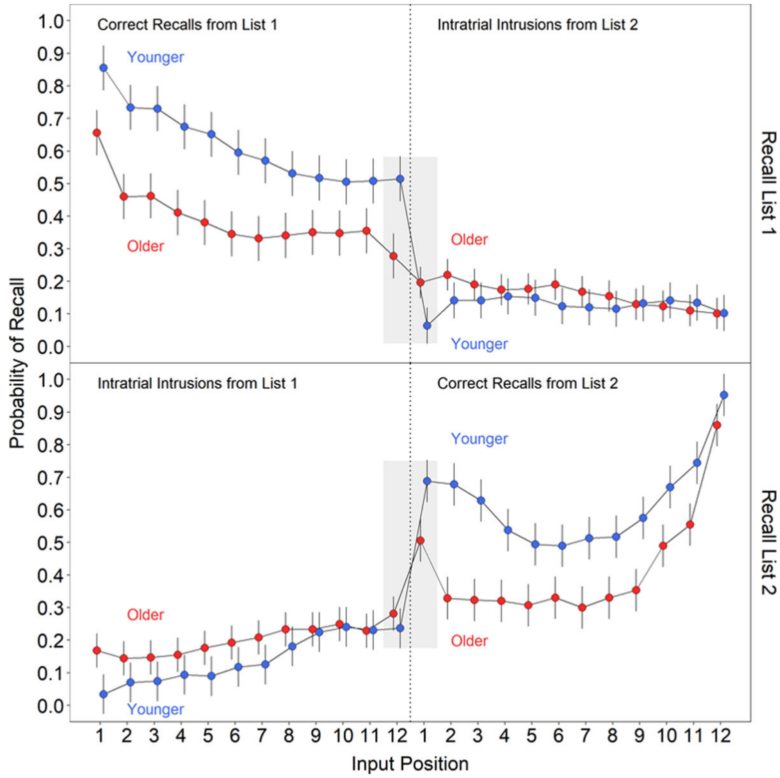

Figure 3. Serial Position Curves for Correct Recalls and Intratrial Intrusions

Note. Smoothed serial position curves displaying model-estimated mean frequencies of correct recalls and intratrial intrusions as a function of input position for tests of List 1 (top panels) and List 2 (bottom panels) for younger and older adults. The gray shaded box highlights the connection between correct recalls from the last serial position and intratrial intrusions from the first serial position (Recall List 1; top panels) and intratrial intrusions from the last serial position and correct recalls from the first serial position (Recall List 2; bottom panels). Error bars are 95% confidence intervals.

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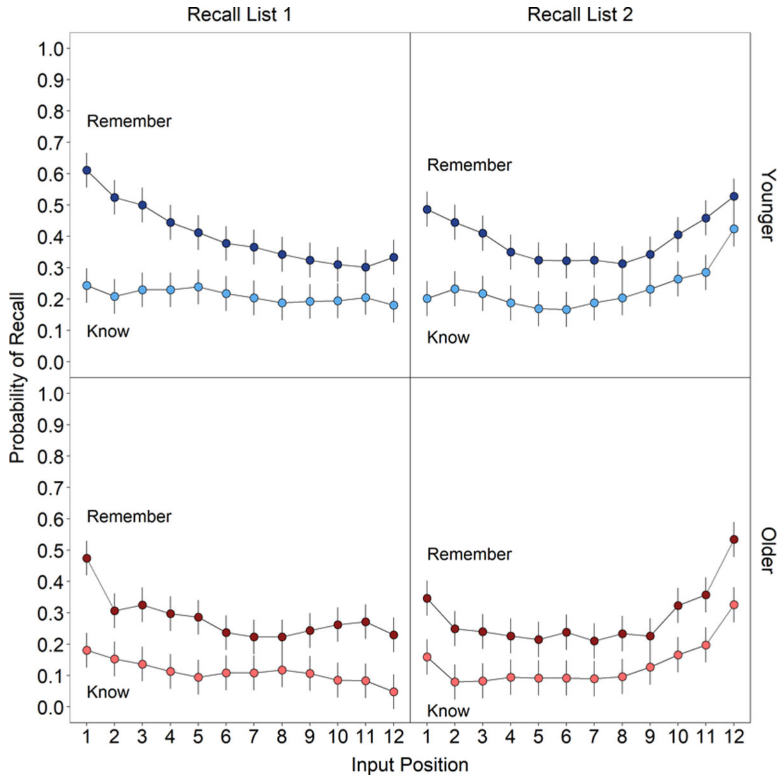

Figure 4. Serial Position Curves for Correct Recalls Conditionalized on Remember/Know Judgments

Note. Smoothed serial position curves displaying model-estimated mean frequencies of correct recalls as a function of input position conditionalized on remember (darker points) and know judgments (lighter points) for tests of List 1 (left panels) and List 2 (right panels) for younger and older adults. The probabilities for the remember and know functions sum to the overall probabilities for correct recalls displayed in Figure 3. Error bars are 95% confidence intervals.

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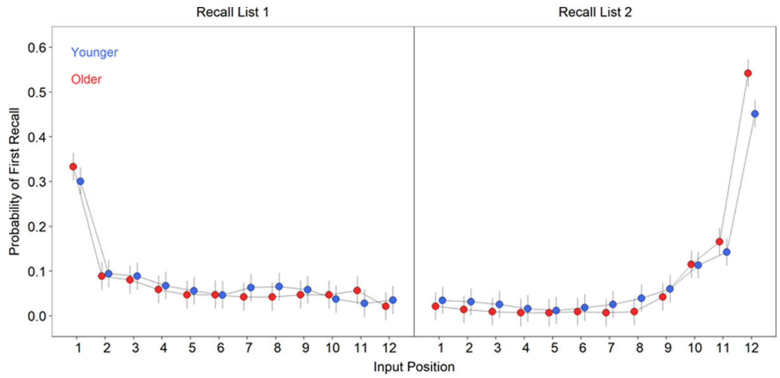

Figure 5. Probability of First Recall Curves

Note. Smoothed probability of first recall curves displaying model-estimated mean frequencies of first-recalled items as a function of input position for tests of List 1 (left panel) and List 2 (right panel) for younger and older adults. Error bars are 95% confidence intervals.

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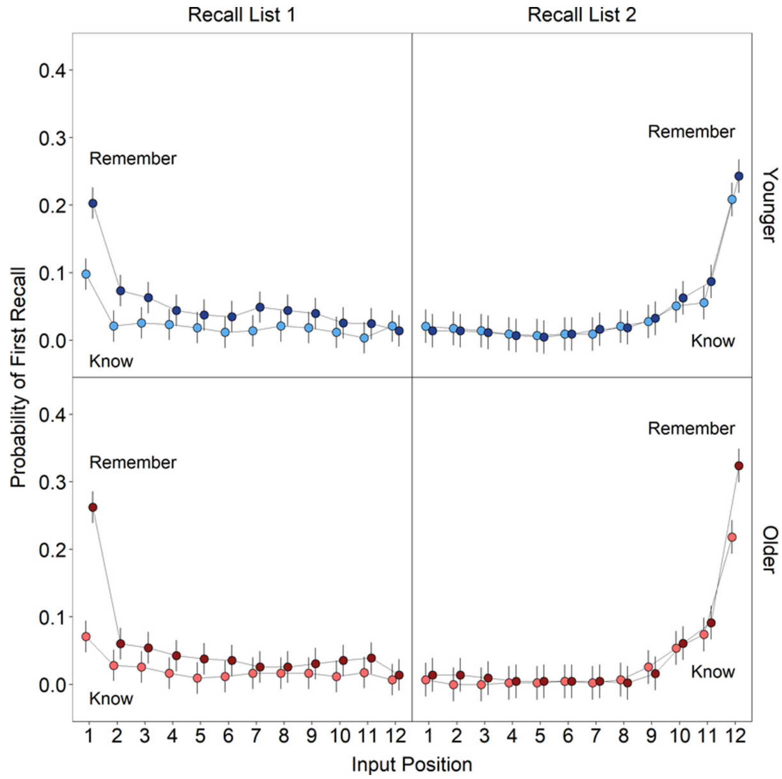

Figure 6. Probability of First Recall Curves Conditionalized on Remember/Know Judgments

Note. Smoothed probability of first recall curves displaying model-estimated mean frequencies of first-recalled items as a function of input position conditionalized on remember (darker points) and know judgments (lighter points) for tests of List 1 (left panels) and List 2 (right panels) for younger and older adults. The probabilities for the remember and know functions sum to the overall probabilities displayed in Figure 5. Error bars are 95% confidence intervals.

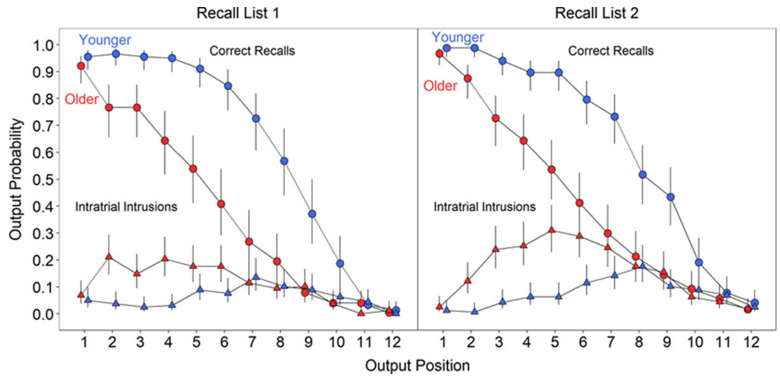

Figure 7. Output Profiles for Correct Recalls and Intratrial Intrusions

Note. Output profiles displaying model-estimated mean output frequencies of correct recalls (circles) and intratrial intrusions (triangles) for tests of List 1 (left panel) and List 2 (right panel) for younger and older adults. Error bars are 95% confidence intervals.

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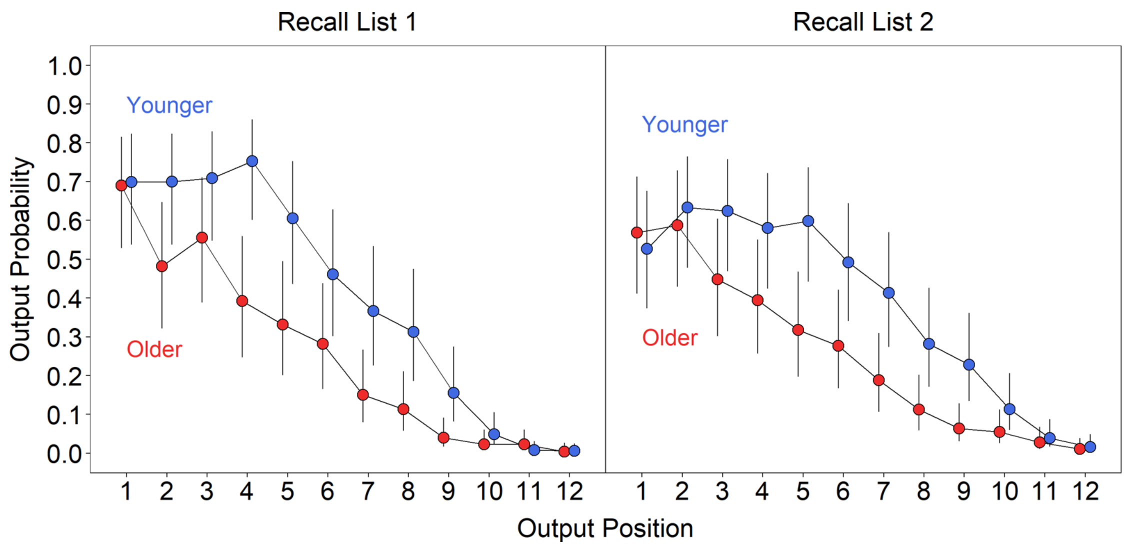

Figure 8. Output Profiles for Remember-Correct Recalls

Note. Output profiles displaying model-estimated mean output frequencies of correct recalls conditionalized on remember judgments for tests of List 1 (left panels) and List 2 (right panels). Error bars are 95% confidence intervals.